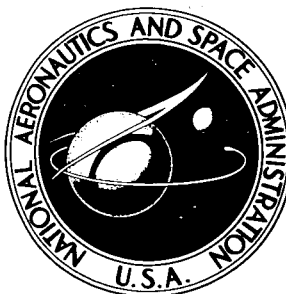


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by Tatsuzo Obayashi

*Goddard Space Flight Center
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SUMMARY

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Some highlights of the recent advent of magnetospheric studies are reviewed. The magnetospheric boundary, where the solar plasma interacts with the outer geomagnetic field, is discussed using various results of magnetic field and plasma measurements made by space probes. The observed spatial profile of ionized particle density and its implication to magnetospheric physics are also given.

Author

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INTRODUCTION

In recent years there has been growing interest in the fringe region of the terrestrial magnetosphere, where the interplanetary gas interacts with the outer geomagnetic field. Several deep space probes have successfully measured the nature of existing plasma and magnetic fields in this region, in particular, Explorer series satellites (X, XII, XIV, and XVIII) provided us most important results.

The main feature of the outer geomagnetic field is summarized in Figure 1, in which the radial profile of the total magnetic field along the sun-earth line is illustrated schematically (References 1-3). As has been expected, the strength of the geomagnetic field decreases with distance from the earth as the inverse-cube law. This relation generally holds in the region out to several earth's radii, however, with increasing distance, the field exceeds the predicted dipolar value in the sunward side, while it is suppressed in the midnight side. The enhanced field in the sunward side collapses suddenly near a distance of $10a$ (a ; radius of the earth). An abrupt change of direction and field strength occurs within a distance of several hundred kilometers. Beyond this

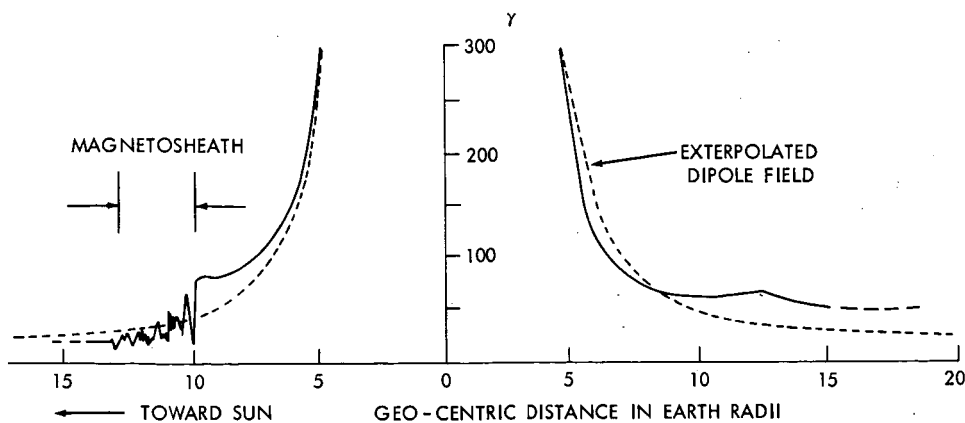


Figure 1—Schematic representation of the outer geomagnetic field in the equatorial plane along the sun-earth line.

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magnetospheric limit, turbulent magnetic fields are observed, which merge gradually into a rather quiescent interplanetary field. Such a transition region, which is called the magnetosheath, extends 3 - 5a ahead of the magnetosphere at the sub-solar direction. In the anti-solar direction, however, there seems to be no sharp boundary. The field is slightly below the theoretical value up to the distance of 6 - 8a and then it rather stays steady beyond this distance.

SHAPE OF GEOMAGNETIC BOUNDARY

The general shape of this geomagnetic boundary has been inferred from various space probe data from 1958 to 1961, which is illustrated in Figure 2 (Reference 4). The orbits of space probes are projected on the earth's equatorial plane in a frame fixed with respect to the direction of the

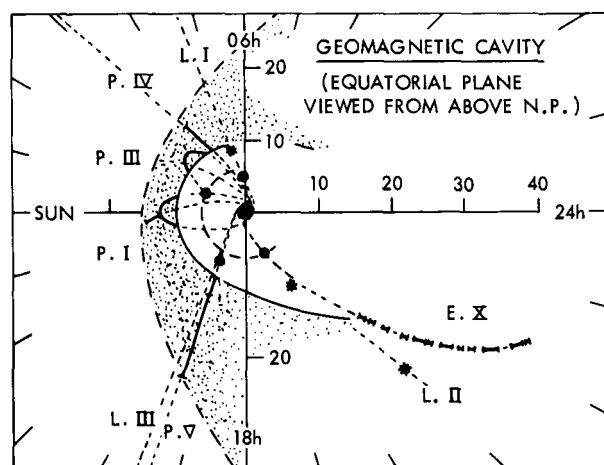


Figure 2—Boundary region of the outer geomagnetic field estimated from various space probe observations.

sun, and the estimated location of the magnetosheath, in which turbulent magnetic fields are characteristic, is indicated by heavy lines along their orbits. It is evident that the boundary of the magnetosphere (geomagnetic cavity) is hemispherical with a radius of about 10a on the sunward side and that an elongated tail is formed on the night side. The frontal surface of the magnetosheath is nearly hyperbolic with the axis to the sun-earth line, being tilted slightly towards the west. The striking feature evident from this illustration is that the shape of the magnetospheric boundary is very similar to that of supersonic aerodynamic flow around a blunt body, which will be discussed again in the following.

THERMAL PLASMA IN MAGNETOSHEATH

Another important nature of the magnetosheath is that the region is filled with a hot thermal plasma of the order of 1 kev, which has been well established by Explorer XVIII measurements (Reference 5). It has already been demonstrated by the Mariner II experiment (Reference 6) that the solar wind, a well directed plasma flux, is continuously streaming out from the sun into interplanetary space with typical values of the bulk velocity range from 250 - 600 km sec⁻¹. The new fact, discovered by Explorer XVIII, is that the anisotropic solar plasma flux is destroyed in the magnetosheath, being converted into a hot isotropic plasma flux with an average energy flux per particle of about 1 kev. The observational evidence showing this effect is reproduced in Figure 3, in which the maximum and minimum fluxes observed during each revolution of the satellite spin are plotted along its orbit across the magnetosheath. Beyond the distance of 17a, the result suggests a strong anisotropy, and the portion of maximum flux has been identified as the direction

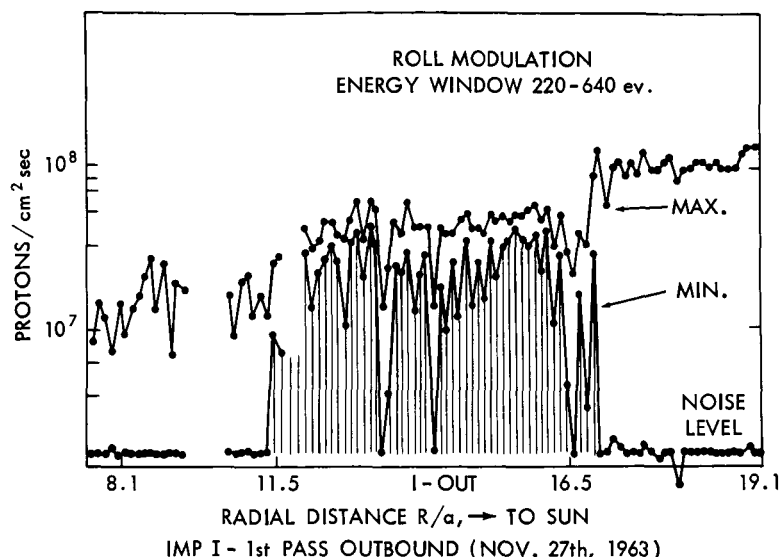


Figure 3—Plasma measurements by Explorer XVIII, showing the plasma flux change across the magnetopause. The separation between the maximum and minimum flux level due to the roll modulation is a measure of the anisotropy of the plasma flux (Reference 5).

toward the sun. On the other hand, the region of the distances of 11 - 17a is turbulent and the isotropy of flux seems to be attained, being indicated by almost equal flux to any direction.

This hot plasma region observed by Explorer XVIII during November 1963 to February 1964 is mapped in Figure 4 on the earth's equatorial plane in a frame fixed relative to the solar direction. The hot plasma region mapped here is exactly correlated with that of turbulent magnetic fields measured by Ness (Reference 3). The agreement with the previous estimate of the shape of the magnetosheath (Figure 2) is also excellent. Now, it is evident that the standing shock theory of the supersonic solar plasma impacting against the geomagnetic field, which has originally been proposed by Axford (Reference 7) and Kellogg (Reference 8), is established on the rigid observational support. The frontal surface of the magnetosheath is, thus, identified as the shock front. The existing shock must be of the collision-free type, and some nonlinear interactions of waves will produce the randomization of particle motions behind the shock front, thereby give rise to the isotropy of particle fluxes. However, the complete understanding of collision-free hydromagnetic shock and the theory of the geomagnetic cavity formation must await further theoretical as well as experimental studies.

The plasma inside the magnetosphere consists of high energy trapped particles and low energy particles (thermal plasma). The former is known as Van Allen particles and its distribution in the magnetosphere has been surveyed extensively by Explorer XII and XIV (Reference 9). In Figure 5, a graphical map of the flux of Van Allen electrons ($E \geq 40$ kev.) is shown. Remarkable features revealed here are as follows: A sharp boundary or termination of the flux at approximately 10a on the sunward side of the magnetosphere and at approximately 8a on the night side.

Thus, the spatial distribution of energetic trapped electrons reveals an asymmetric nature, and this suggests that drift motions of particles due to polarization electric fields may be effective for the gross shape of the trapped particle distribution. The relevant electric field may arise from the large-scale distortion of the outer geomagnetic field (Reference 9) or from ionospheric current systems (Reference 10).

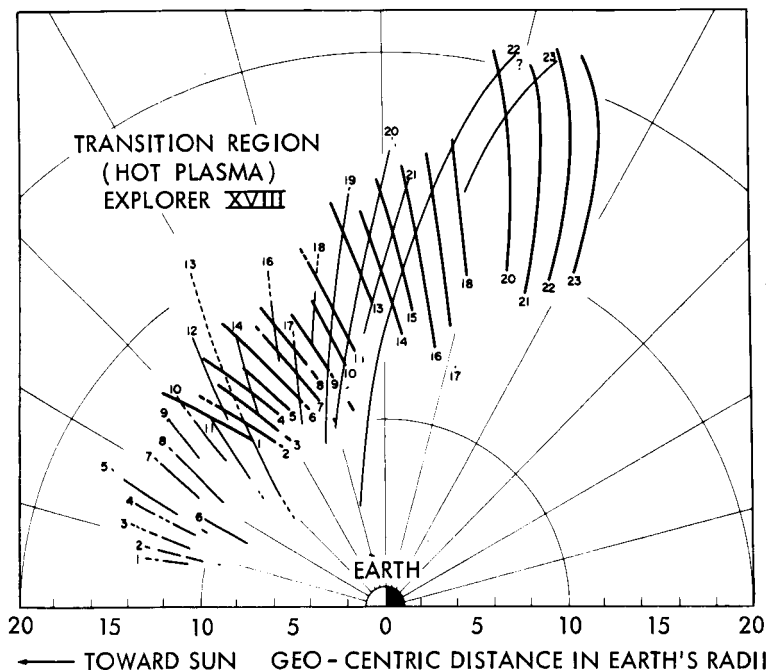
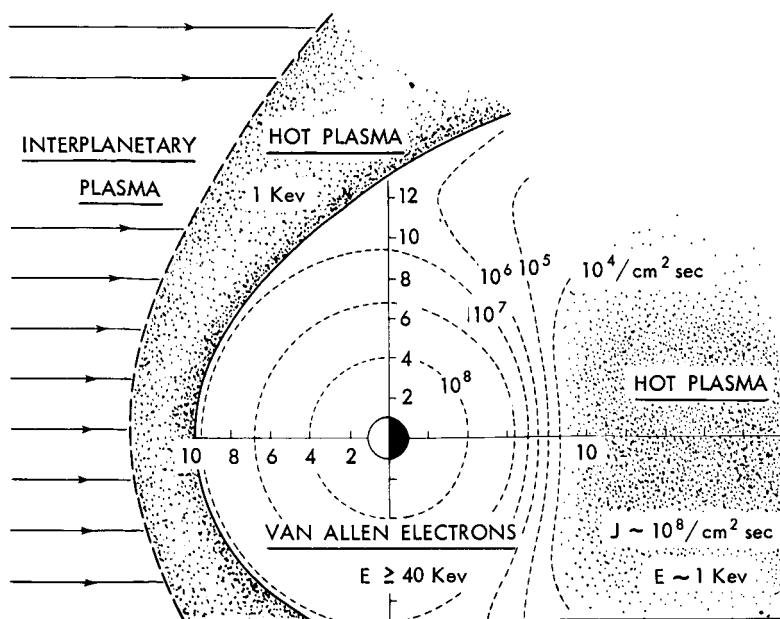


Figure 4—Locations of isotropic hot plasma fluxes observed by the Explorer XVIII satellite during the period of November 27, 1963 to February 24, 1964 (Reference 5).

Figure 5—Graphical summary of measurements of energetic electrons ($E \geq 40$ kev) and of hot plasmas ($E \sim 1$ kev) in the geomagnetic equatorial plane (Reference 9).



THERMAL PLASMA IN OUTER MAGNETOSPHERE

A hot plasma similar to the one in the magnetosheath on the sunward side has also been observed by Lunik II and Explorer X in the night side of the outer magnetosphere. It is interesting to note that Explorer XIV has encountered energetic electrons ($E \gtrsim 1$ kev) with sporadically enhanced fluxes on the night hemisphere outside the regular trapping region, particularly, along the solar ecliptic plane. The approximate position of such hot plasma is also indicated in Figure 5.

For the low energy thermal plasma of a few ev., very few satellite measurements are available at present. Gringautz (Reference 11) reported the plasma ion density profile in the magnetosphere obtained by Lunik I, II and III, those which traversed high latitude paths, while Explorer XVIII revealed the thermal electron flux along its equatorial orbit (Reference 12). On the other hand, very reliable results have been obtained from systematic vlf whistler analyses using ground-based observation data (Reference 13). These results are summarized in Figure 6.

It is known from the whistler study that the electron density beyond the ionosphere falls off as the inverse-cube law of the geocentric distance, which is, then, proportional to the gyro-frequency of the respective region. However, an edge occurs at a distance of about $4a$, beyond this a steeper gradient being estimated. The result of Explorer XVIII showed a similar sharp decrease at about the same distance. Further out of this edge, the average electron energy then increases gradually from the thermal energy to values above a few hundred ev. near the magnetospheric boundary. The result obtained by Lunik II, which may be representative of the profile at high latitudes, indicates considerably lower density compared with that of low latitudes and the density decreases very slowly up to the distance of $4a$, at where the effect of a similar edge appears again. The discrepancy of these two profiles at high and low latitudes may be significant, and this would suggest some substantial difference existing in the magnetosphere.

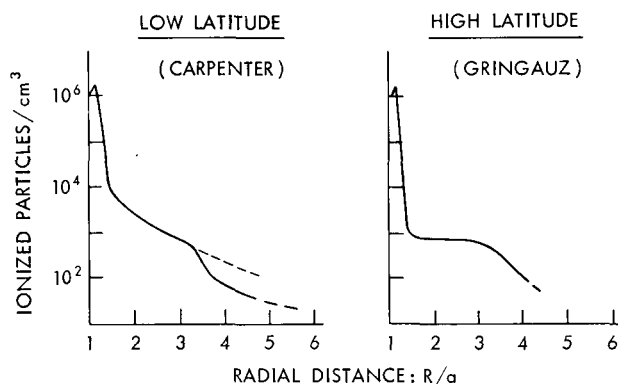


Figure 6—Ionized particle density profiles in the magnetosphere at high and low latitude regions.

CONCLUSIONS

Although the observational materials are still incomplete and it may be too early to offer any theory for such plasma density profiles, we may predict that the observed result might be related to some extent to the temperature distribution in the magnetosphere. The thermal temperature of the magnetosphere in high latitude is expected to be considerably higher than that of low latitudes, because of a large anisotropic nature of the thermal conductivity and of overwhelming high temperature in the magnetopause or interplanetary space. These facts of particle density

distributions as well as the temperature and particle energy spectrum must be taken into account for further discussions of the hydromagnetic phenomena in the magnetosphere.

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